NASA TN D-1755

N63 18657

NASA TN D-1755

TECHNICAL NOTE

D-1755

SOME ASPECTS OF STRATOSPHERIC CIRCULATION DERIVED FROM METEORLOGICAL ROCKET FIRINGS OVER THE UNITED STATES DURING THE WINTER OF 1961

Mohammad Rahmatullah
Goddard Space Flight Center
Greenbelt, Maryland

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON July 1963

SOME ASPECTS OF STRATOSPHERIC CIRCULATION DERIVED FROM METEOROLOGICAL ROCKET FIRINGS OVER THE UNITED STATES DURING THE WINTER OF 1961

by
Mohammad Rahmatullah
Goddard Space Flight Center

SUMMARY

Data from six rocket launching sites in North America obtained from a series of meteorological rocket firings conducted between January 16 and February 23, 1961, were analyzed. Time cross-sections of winds at Wallops Island, Virginia, and Cape Canaveral, Florida, are presented and discussed in the light of synoptically significant situations as determined by the 10 mb chart. Temperature soundings in the lower stratosphere relevant to the typical situations are also considered. TIROS II ($1960\,\pi 1$) radiation data for orbits 827 and 957 have been analyzed in order that the effect of ozone on stratospheric disturbances might be studied. It was found that the penetration of the mesospheric westerly jet to lower levels was associated with the formation of a marked trough of low pressure over the eastern United States and coincided with the occurrence of a severe cold period. No final stratospheric warming was observed and by mid-February the westerlies were back to full strength. A microstructure of the mesodecline at 63 km was observed at Wallops Island and at White Sands, New Mexico. The analysis of TIROS II radiation data pointed out that the effect of changes in the ozone layer is completely masked by the varying cloud pattern.

CONTENTS

SOME ASPECTS OF STRATOSPHERIC CIRCULATION DERIVED FROM METEOROLOGICAL ROCKET FIRINGS OVER THE UNITED STATES DURING THE WINTER OF 1961

by

Mohammad Rahmatullah*

Goddard Space Flight Center

INTRODUCTION

This paper is primarily concerned with the study of stratospheric circulation over North America in the light of wind and temperature measurements from a series of meteorological rocket firings conducted between January 16 and February 23, 1961. The rocket results were reported by the Interrange Instrumentation Group (IRIG) in their quarterly report for the winter firings of 1961 and were prepared by the U.S. Army Signal Missile Support Agency, White Sands, New Mexico (Reference 1). Data from six meteorological rocket launching sites in North America were studied: Cape Canaveral, Florida; Fort Churchill, Manitoba, Canada; Point Mugu, California; Tonapah Range, Nevada; Wallops Island, Virginia; and White Sands, New Mexico. The rockets fired include Arcas-Loki I and II and Hasp systems. The payloads were Robin spheres, parachute sondes, and Chaff. These rocket systems are supposed to provide wind measurements from 15 to 75 km, and the parachute sonde system, in addition, takes temperature measurements.

The operational problems involved in firing rockets, such as weather conditions, range safety, etc., make a synoptic firing schedule difficult. Therefore, the time interval chosen has to be based on the coincidence of the following factors: (1) the occurrence of a synoptically significant situation, as determined by the 10 mb charts; and (2) the availability of rocket data and other relevant information such as the radiation data from TIROS II (1960 π1). The primary objective in the present case was to study the polar vortex as related to the changes in temperature and wind pattern recorded by the various rocket firing ranges. It was also conceived that both the TIROS II radiation data collected during this period, and also temperature and wind data from a rocket grenade experiment fired on February 16, 1961, at Wallops Island might contribute to the analysis.

*This paper was written while Mr. Rahmatullah, regularly of the Pakistan Meteorological Department, was in residence at Goddard Space Flight Center under an international cooperation program.

UPPER AIR CIRCULATION OVER NORTH AMERICA DURING JANUARY AND FEBRUARY OF 1961

The wind circulation in the stratosphere is generally governed by the polar-night vortex. The breakdown of the polar vortex is accompanied by some remarkable changes, of which the most important is perhaps the explosive stratospheric warming, first observed by Scherhag in 1952 (Reference 2). Rocket grenade measurements of temperature and winds over Fort Churchill, Canada, in January 1958 have shown that stratospheric circulation breakdown and associated warming were preceded by a breakdown of circulation throughout the stratosphere and lower mesosphere (Reference 3). Teweles and Finger have also studied this phenomenon thoroughly for January 1958 and have found that the temperature south of Greenland rose from -70° to -39°C in a period of 4 days and that this rise was associated with major changes in the upper air circulation (Reference 4). Generally, it has been observed that the polar vortex is not fully restored after a breakdown in the stratospheric circulation.

During January 1961 the upper air circulation at 10 mb over North America was greatly affected by the eastward movement of an anticyclone from the Alaskan region to the Hudson Bay area on January 9. The intensity of this anticyclone was weak compared to that of one in the previous year in which the height of the 10 mb surface over the Bering Strait reached values as high as 3192 geopotential decameters between January 7 and 11 (Reference 5). The anticyclone of 1961 retreated to the Aleutian region and it finally disappeared by the end of January. Circulation at the 10 mb level over most of Canada and the United States on January 17, 1961, was dominated by the retreating anticyclone (Figure 1).

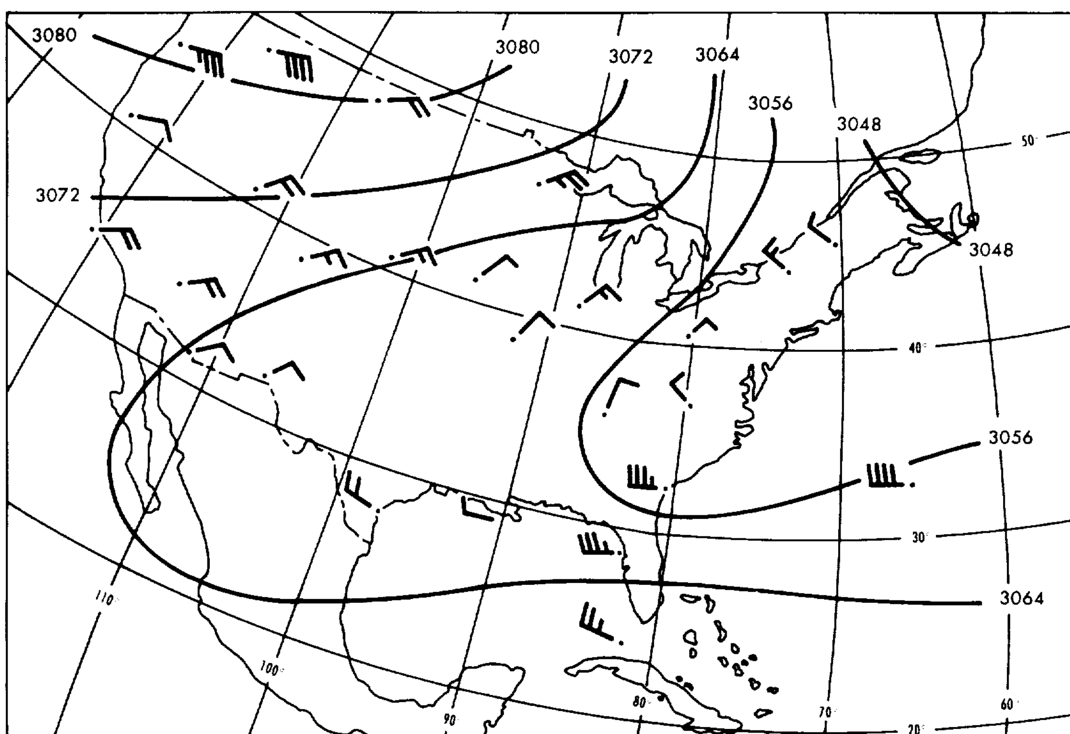


Figure 1—Circulation at the 10 mb level, January 17, 1961.

The weakening of the Aleutian high resulted in the migration of the cold vortex from Siberia to the Canadian sector of the Arctic during the last 10 days of January 1961. Initially a trough of low pressure developed which extended from Greenland to Labrador; later it formed into a separate cyclonic cell. Labitzke-Behr et al. pointed out that this cell, contrary to the main vortex, showed a warm core with temperatures up to −40°C, reached on January 25 (Reference 5). The synoptic pattern at the 10 mb surface for January 26, 1961, is illustrated in Figure 2. On this date the eastern half of the United States was clearly under the influence of the cyclonic vortex. Circulation over the Pacific Coast and the adjoining Rockies was anticyclonic. By the end of January the wind circulation over the United States at the 10 mb level had become strongly zonal. Gradually the zonal flow weakened and by the first week of February a weak shear which had been over the Great Lakes region was moving eastward over the Atlantic seaboard. Then the anticyclonic circulation again developed over most of the western United States under the influence of a new Aleutian high which had been established on February 12. A typical example, illustrating this regime for February 16, is given in Figure 3.

TIME CROSS-SECTION OF WIND AT WALLOPS ISLAND, VIRGINIA

Wallops Island is the only rocket firing range representative of the middle latitudes in the eastern United States. Rocket wind data from Fort Churchill, Canada, were available for 1 day in January and 6 days in February 1961. Since most of the latter firings did not exceed the height of 30 km, they were of limited use in this study. The time cross-section of zonal winds over Wallops Island is given

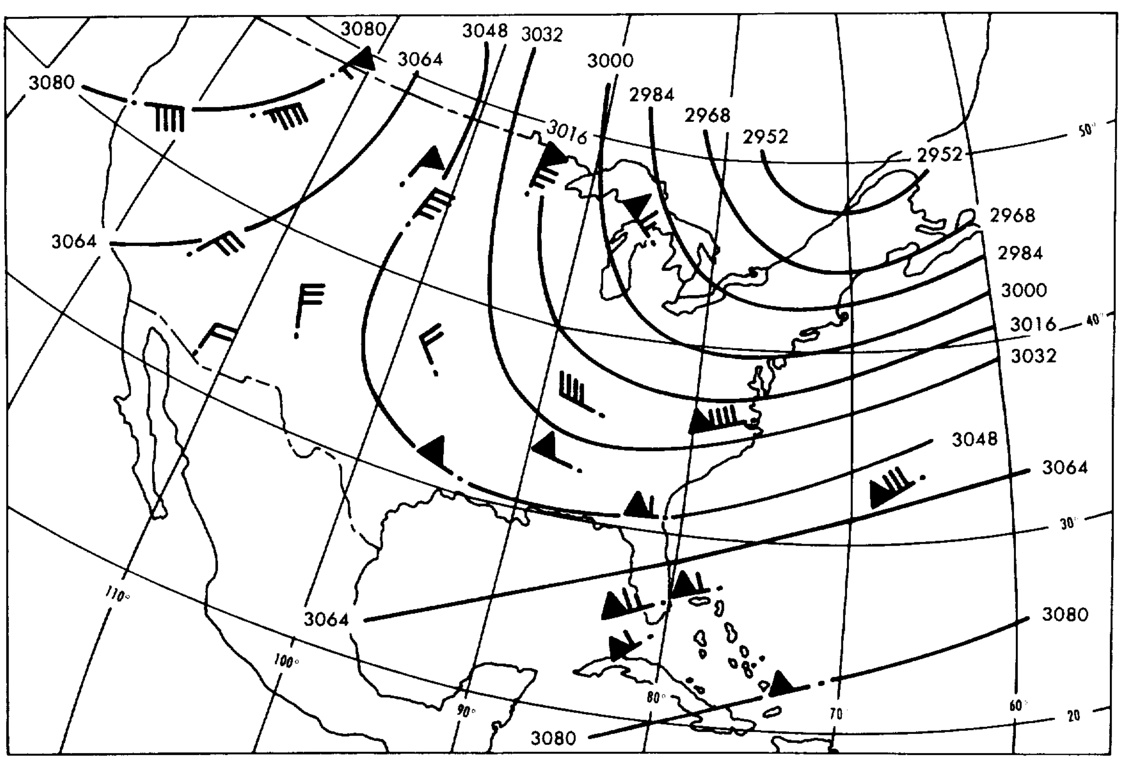


Figure 2—Circulation at the 10 mb level, January 26, 1961.

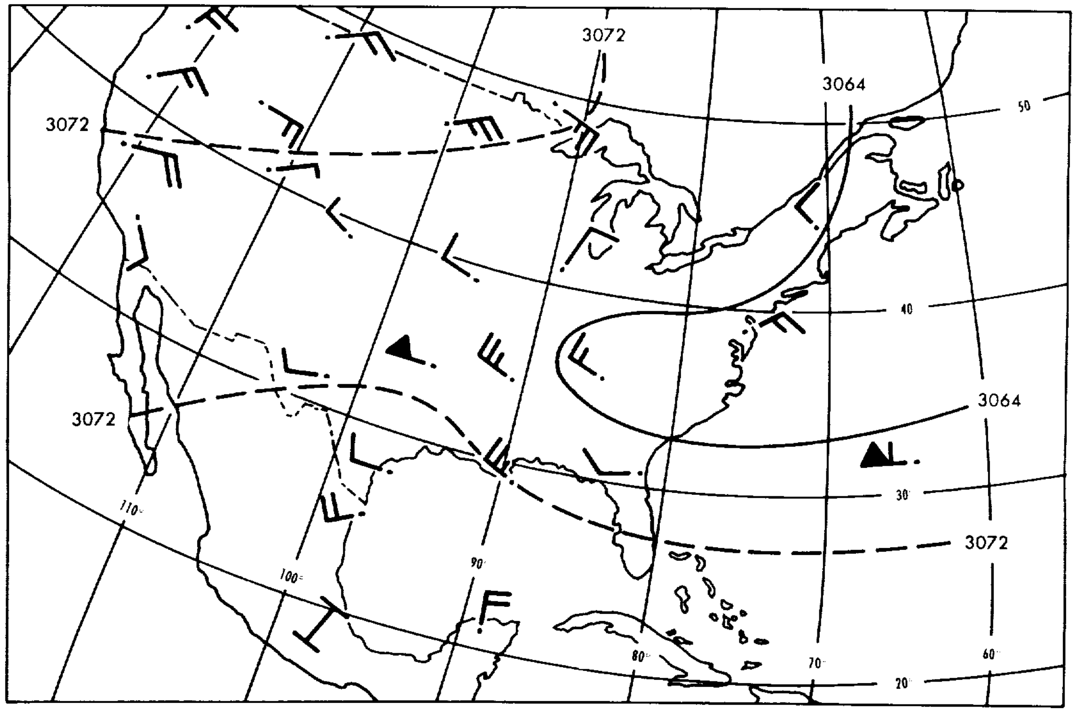


Figure 3—Circulation at the 10 mb level, February 16, 1961.

in Figure 4. It is obvious that the wind structure as revealed by this time cross-section is quite different from the mean zonal cross-section as computed by Murgatroyd (Reference 6). Recently Batten, in the light of the discovery of the phenomenon of explosive warming observed in the months of January and February, tried to compute separate mean cross-sections for November to December and January to February (Reference 7). He also incorporated all available rocket data in his computation. The winter cross-section for Wallops Island for 1961 shows fair agreement with Batten's zonal cross-section in that the tropospheric westerlies are bounded by a region of weak easterlies or zones of calm wind. However, two points stand out strikingly in contrast to Batten's model of mean zonal flow. The first is the penetration of the westerly maximum in the stratosphere to a level of about 35 km on or about January 25, 1961, and the second is the predominance of strong easterly flow during the last days of January. The highest velocity of the easterly wind recorded for the last days of January was 100 knots near 45 km on January 31, 1961. During February the flow, though variable from day to day, generally corresponded to the standard winter pattern in which the westerlies are strong and increase with height. Apparently in this case, contrary to the previously observed breakdowns of the polar vortex, the polar westerlies returned to full strength. It is noteworthy that during the period of study no explosive warming in the stratosphere was observed. The penetration of strong westerlies to lower altitudes, near the stratosphere, about January 25, was associated with the presence of a deep trough over the eastern United States and Labrador at the 10 mb level. It is interesting that the severe cold and blizzardous period observed in the winter of 1961 coincided with the penetration of strong westerlies to the low stratospheric levels.

In considering the zonal maximum of the easterlies at about 45 km on January 31, 1961, it appears that the development of the warm core cyclonic cell near Labrador may have been influential in changing the flow pattern, since the presence of warm air to the north of Wallops Island would have given rise to thermal wind effects tending to cancel the westerly zonal flow. However, in the absence of temperature data over Wallops Island for that date, this interpretation may be taken as purely tentative.

The time cross-section for meridional winds at Wallops Island is given in Figure 5. It indicates that southerly winds predominate in the upper stratosphere. The lower stratosphere is marked by

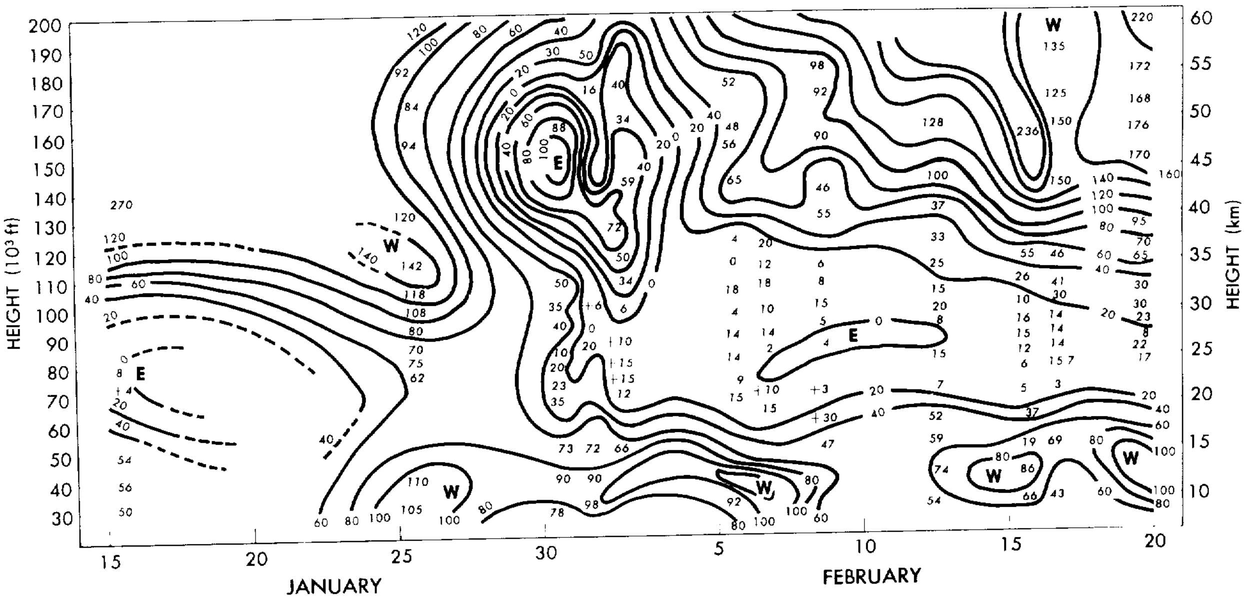


Figure 4—Time cross-section of zonal winds (knots), Wallops Island.

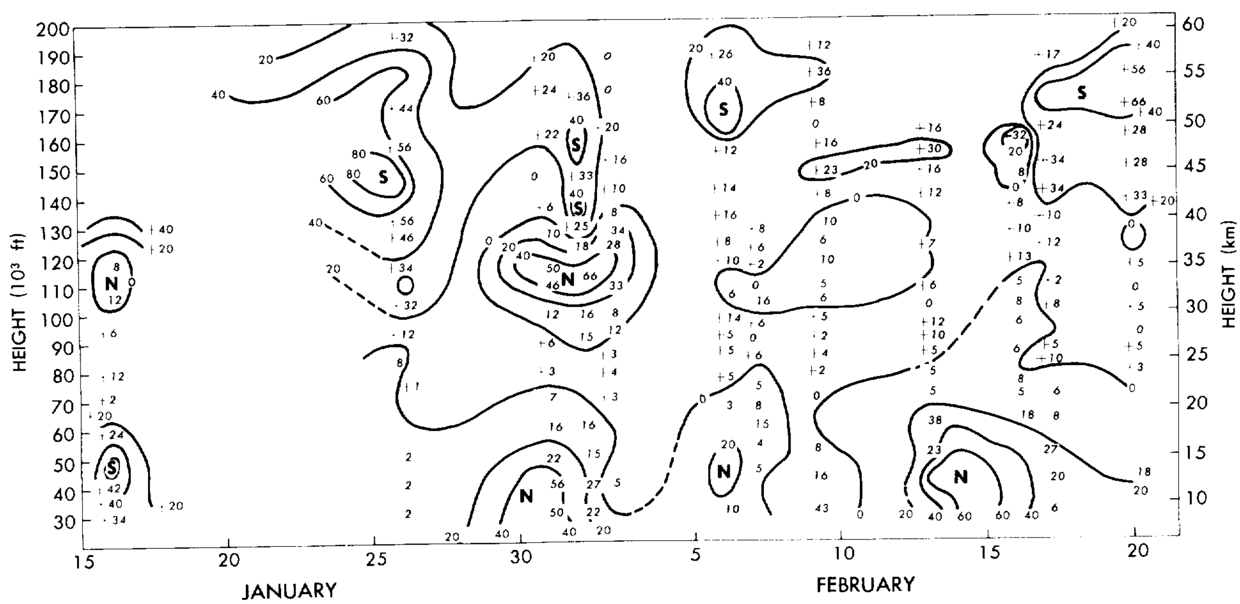


Figure 5—Time cross-section of meridional winds (knots), Wallops Island.

weak variable winds. Meridional flow is not as strong as zonal flow. It can be inferred that the wind circulation in the upper stratosphere is predominantly a zonal flow over which the meridional component has been superimposed in association with upper air wave circulation.

TIME CROSS-SECTION OF WIND AT CAPE CANAVERAL, FLORIDA

The data from Cape Canaveral are limited to the period from January 16 to 25. The time cross-sections of zonal and meridional winds are given in Figures 6 and 7, respectively. These figures show that strong westerly flow was well established at Cape Canaveral during the epoch of westerly wind penetration at Wallops Island. Westerly wind velocity as high as 100 knots was reported from Cape Canaveral on January 25 at about 33 km. The mean wind velocity in Batten's computed cross-section at the latitude of Cape Canaveral is only of the order of 15 to 20 knots. It demonstrates that the stratospheric disturbance is large and its influence on the wind pattern extends at least from 38° to 28°N. As in the case of Wallops Island the predominant meridional wind component in January is from the south. The lower stratosphere is marked by weak variable meridional wind components.

ZONAL WINDS AT WHITE SANDS, NEW MEXICO

The zonal wind pattern for White Sands, New Mexico, has been studied by Keegan (Reference 8), who observed that in mid-January strong westerly winds were reported at approximately 60 km. The

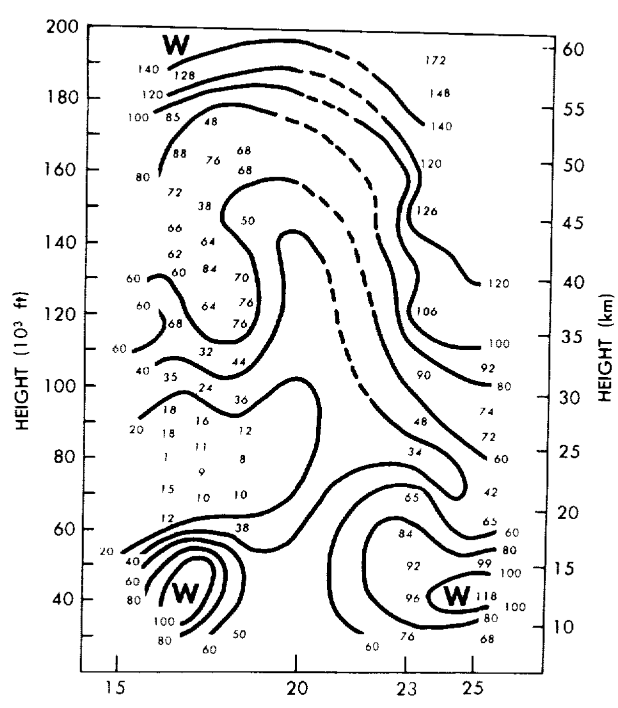


Figure 6—Time cross-section of zonal winds (knots), Cape Canaveral.

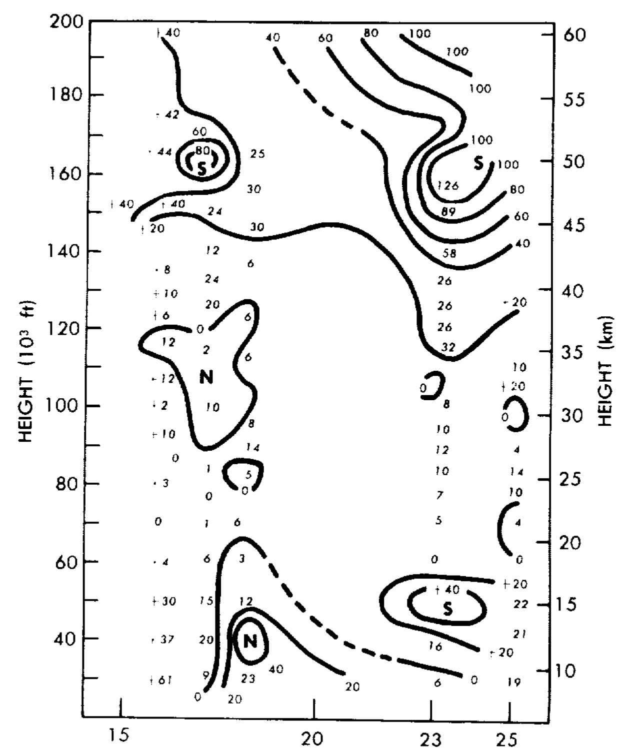


Figure 7—Time cross-section of meridional winds (knots), Cape Canaveral.

zonal westerlies decreased after January 18 and reached a minimum between January 20 and 23. By January 26 the zonal westerlies were re-established at White Sands with 100 knot winds at about 36 km. Thus, the stratospheric disturbances which affected Wallops Island also caused the strengthening of westerly wind at White Sands. The influence of the stratospheric disturbances was only lightly felt at Point Mugu.

TEMPERATURE SOUNDINGS

Rocket temperature data for the period in consideration were available only from Cape Canaveral, Fort Churchill, Point Mugu, and, occasionally, White Sands. Temperature data from one rocket grenade firing on February 16 were available, from Wallops Island (Reference 9). Therefore, it was difficult to find suitable dates for which data from more than two or three stations could be used to correspond to the synoptic situation as illustrated in Figures 1-3. The close agreement between temperature data obtained from rocket firings and from radiosondes inspired confidence in analyzing at least one cross-section, for January 17-18, for which temperature data from Cape Canaveral, Point Mugu, and White Sands were available. For January 26 and February 16 rocket temperature data from two stations, as available, were plotted in order to compare the stations in regard to the temperature field in the stratosphere and lower mesosphere.

The temperature cross-section for January 17-18 is given in Figure 8. The time of the rocket firing for Cape Canaveral was in the evening, whereas the firings for White Sands and Point Mugu

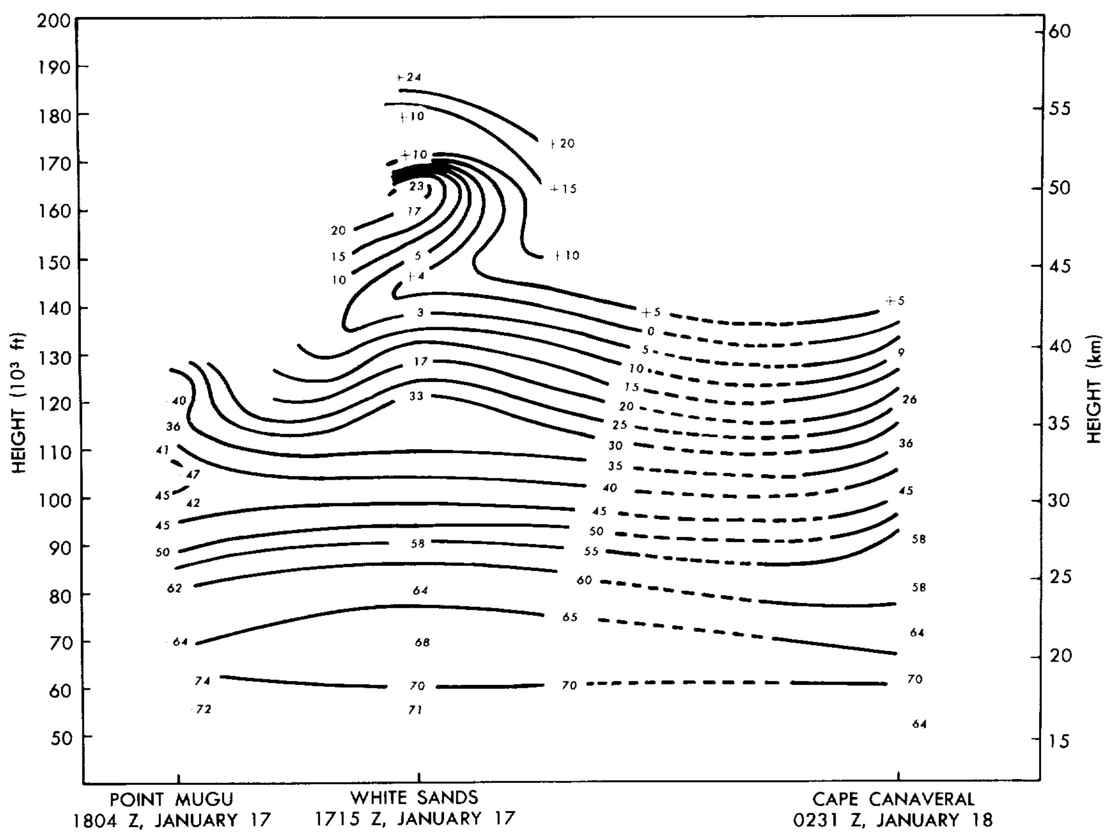


Figure 8—Temperature cross-section for Cape Canaveral, White Sands, and Point Mugu.

were in the morning. In general, temperatures at White Sands were lower than at Cape Canaveral above about 36 km. These two ranges used the same sensors. There were no significant temperature differences between 15 and 36 km. The temperatures between 18 and 32 km were consistently higher at Point Mugu than at White Sands, possibly due to the fact that the two ranges used different sensors. The temperature recorded at 44 km, near the mesopeak, at White Sands was 4 C. Thereafter, the temperature decreased to about 50 km, when it started rising again. This peculiarity has been found in the winter soundings of higher latitudes. However, data should be interpreted with the understanding that these temperature sensors are very close to their limit of reliability at altitudes above 50 km.

Temperature data from rockets fired on January 26, 1961, are plotted in Figure 9. Upper air temperature data from White Sands are not available for this date, but it can be assumed that the temperature pattern there would not be substantially different from that at Point Mugu. It can be inferred that the disturbance which affected the United States in the fourth week of January caused appreciable temperature differences from east to west between 25 and 33.5 km in the lower latitudes.

The temperature soundings for White Sands and Wallops Island (rocket grenade data) for February 16 and 17 (Figure 10) can be considered a typical example of a synoptic pattern with no strong cyclonic or anticyclonic patterns over the United States. On the 10 mb chart (Figure 3) a weak trough of low pressure lies over the central United States and a weak anticyclonic pattern prevails over most of the western United States. The temperature data obtained from rocket firings agree so well with RAOB data that no doubt is left regarding their accuracy at the lower altitudes. The temperature in the stratosphere up to 30 km is generally about 5°C higher at Wallops Island than at White Sands. But at about 30 km

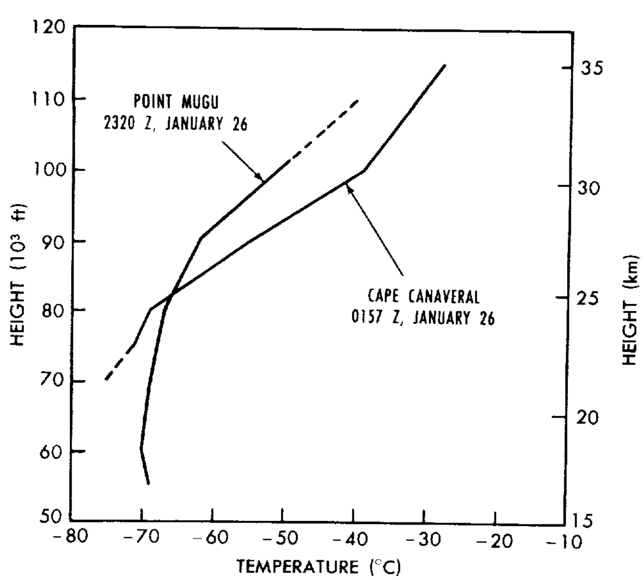


Figure 9—Temperature soundings at Cape Canaveral and Point Mugu.

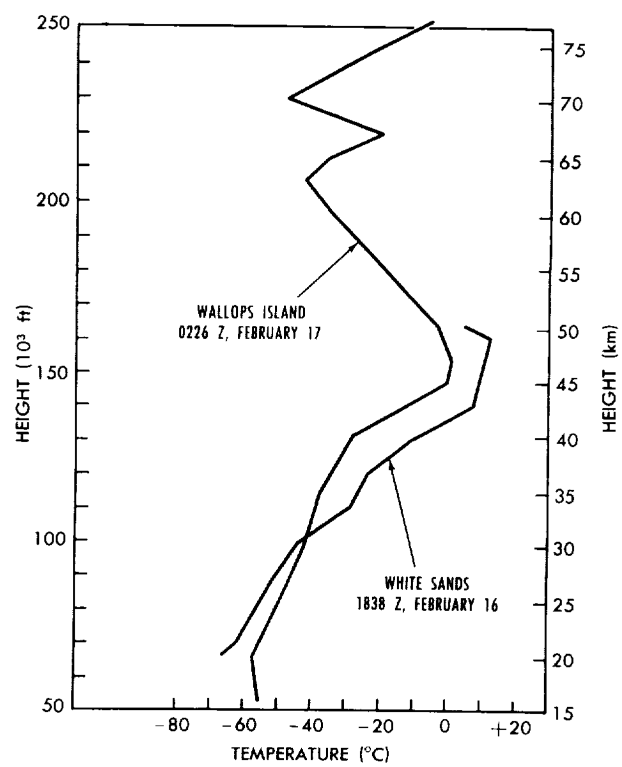


Figure 10—Temperature soundings at Wallops Island and White Sands.

this trend reverses. All of this can be explained on the basis of latitudinal differences between the two places and also is reflected in the mean wind cross-section.

The mesopeak level at White Sands is reached at 46 km; the difference in the mesopeak temperature between White Sands and Wallops Island is 12°C. In the mesosphere the temperature sounding computed from the grenade firing at Wallops Island shows the same trend previously observed at very high latitudes (Reference 3). At 63 km the temperature lapse rate reverses and a rise is experienced to 67 km. The temperature falls again after 67 km until the lowest value, −47°C, is reached at 70 km; it rises thereafter. It is difficult to evaluate the significance of this peculiar behavior of the wintertime temperature structure in the mesophere. Recently Nordberg published results of rocket grenade firings at Wallops Island which definitely confirm the existence of this secondary temperature maximum at these relatively low latitudes (Reference 9).

RADIATION DATA FROM CHANNEL 2 OF TIROS II

In order to study the gross features of cloudiness and temperature conditions over the United States in the different regimes discussed earlier, radiation data obtained from channel 2 of TIROS II for orbits 827 and 957 were studied. Radiation registered by channel 2 (8-12 μ) comes mostly from the ground or from cloud tops. The radiation data of January 18, 1961, obtained for orbit 827 are illustrated in Figure 11. The analysis indicates very low values of radiant emittance, on the order of 14 to 16 watts/m^2, were measured over the north central United States. The thick black lines show the position of the surface front at 2100 Z on January 18, which is fairly close to the time of the passage of the satellite over the United States. Scattered and broken cloud cover prevailed over the eastern states with surface temperatures from about 10°C to 15°C. But over much of the Middle West and Northwest the sky was practically overcast. Cloudiness decreased north of the front, from Wisconsin to the Dakotas, but surface temperatures were still well below freezing. It had been hoped that the TIROS II channel 2 data, which represent radiation received in the 8 to 12 micron region, might reflect some variation in ozone content and distribution which would be related to the circulation phenomena described in the third, fourth, and fifth sections of this report. However, the synoptic situation described above causes such large variations in the temperatures of the emitting levels in the troposphere and at the earth's surface that any changes in the radiative transfer in the stratosphere would be completely masked by these lower level variations. Thus in this study the channel 2 data can be used only to describe the synoptic situation in the troposphere.

The same conclusion holds for orbit 957 on January 27, 1961, although in this case the radiation pattern is much more uniform (Figure 12). Radiant emittances of 20 watts/m^2 cover practically all of the area from the Great Lakes to New England. The sky was overcast over the eastern states at 1800 Z, the closest synoptic hour to the TIROS pass time. Over New England, cloud cover was broken to scattered, with temperatures ranging near -7°C. Around the Great Lakes, cloud cover was scattered to broken with increasing cloudiness toward the Northwest. Surface temperatures varied from −20° to −25°C over most of the Middle West and Northwest. This is the period characterized by the trough on the 10 mb chart over the eastern United States, but it must be concluded that the low radiation values scanned by channel 2 are indicative of the cloudiness and the bitter cold spell

Figure 11—Isolines of radiation (watts/m²), light black lines, for TIROS II orbit 827, 2110 Z, January 18, 1961, for channel 2 (8-12μ). The heavy black lines indicate surface fronts at 2100 Z.

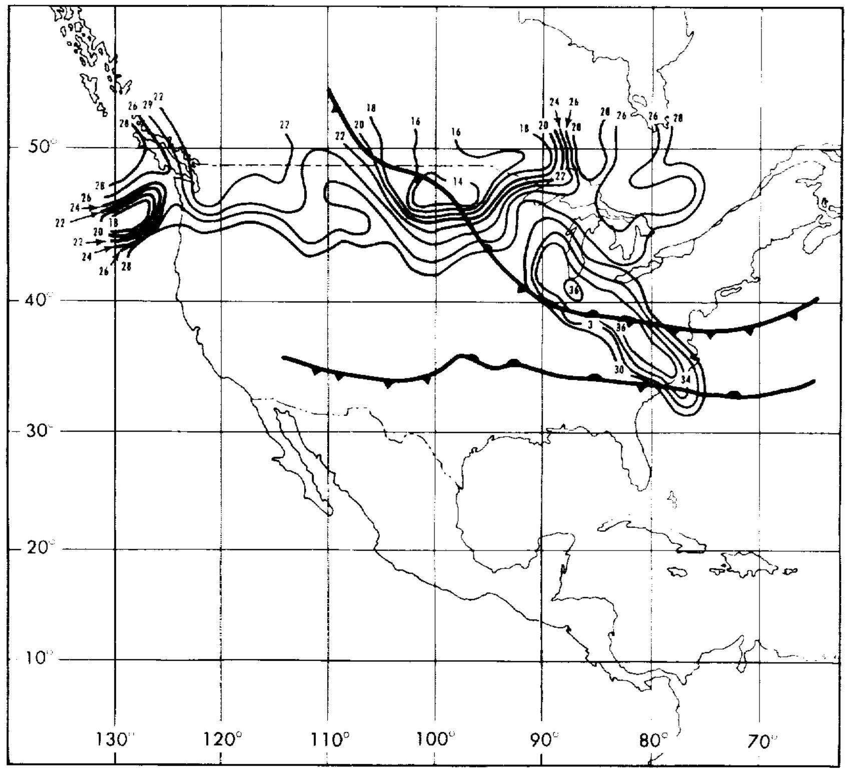
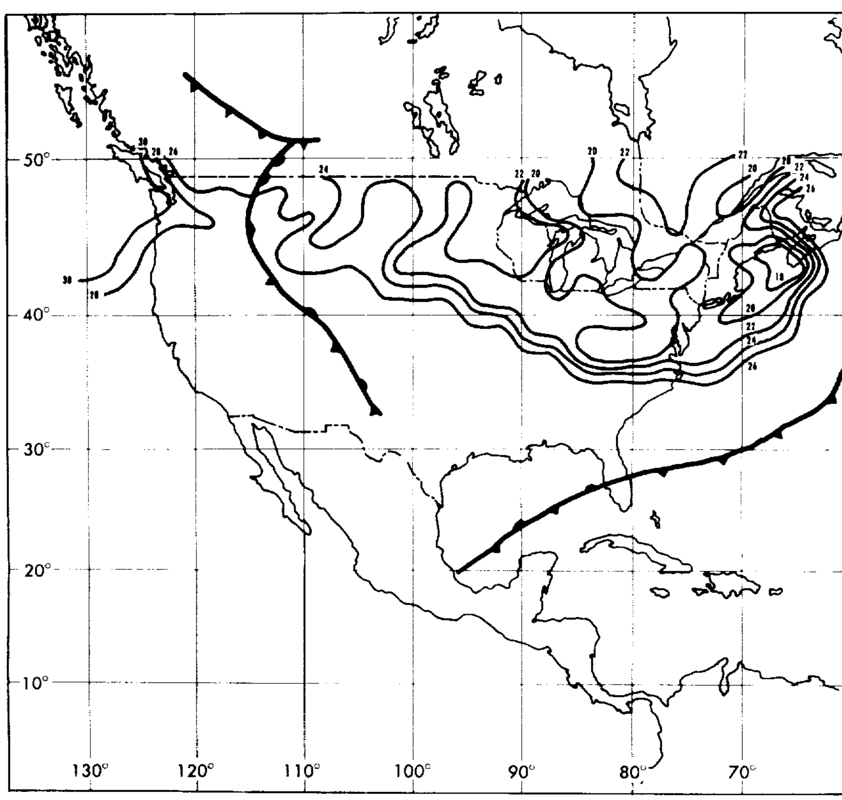


Figure 12—Isolines of radiation (watts/m²), light black lines, for TIROS II orbit 957, 1755 Z, January 27, 1961, for channel 2 (8-12μ). The heavy black lines indicate surface fronts at 1800 Z.



which gripped most of the eastern United States in the fourth week of January. It would have been desirable, of course, to study further the day to day variation in the radiation pattern, but it was not possible in this case because of the change in the orbital position of the satellite.

CONCLUSION

The study of the wind and temperature data from rocket firings during the winter of 1961 brings out the following important facts:

1. The upper stratosphere was subject to wind circulation, reflected on the 10 mb chart, which influenced the upper air circulation over extensive areas in both the north-south and east-west directions. The penetration of the mesospheric westerly jet to lower levels was associated with the formation of a marked trough of low pressure over the eastern United States. This penetration coincided with the occurrence of a severe cold and blizzardous period in that area during the fourth week of January.

2. The weakening of the polar vortex and the associated 10 mb trough ushered in a strong easterly flow which was later replaced by strong zonal westerlies. No final stratospheric warming was observed during the period of study and the westerlies had returned to full strength by the middle of February. This is contrary to the case where stratospheric warming had previously been observed in association with a breakdown of the polar vortex and the westerlies were not fully restored (Reference 4).

3. Circulation changes in the stratosphere and the lower mesosphere affect the ozone content of the atmosphere. This phenomenon has been studied in detail by Wexler (Reference 10). It was thought that the changes in the ozone layer might be reflected in the radiation data obtained for channel 2 of TIROS II for the typical regimes under study. But the radiation data were so greatly influenced by cloud cover that the effects due to changes in the ozone layer were completely masked by it.

ACKNOWLEDGMENTS

The author expresses his thanks to Dr. William Nordberg of Goddard Space Flight Center for assistance and guidance in the preparation of this paper and for making available all the data needed in this study. He is also thankful to Prof. Scherhag for the permission to reproduce Figures 1-3 from the northern hemispherical charts published by the Free University of Berlin. He is indebted to Prof. Abdus Salam, Chairman, Pakistan Space Committee, and Dr. I. H. Usmani, Chairman, Pakistan Atomic Energy Commission, for sponsoring his visit to the United States.

REFERENCES

1. "Data Report of the Meteorological Rocket Network Winter 1961 Firings," U. S. Army Signal Missile Support Agency, White Sands Missile Range, IRIG-MWG No. 6-61, April 1961.
2. Scherhag, R., "Die Explosionsartigen Stratosphärenerwärmungen des Spätswinters 1951/1952," *Berichte des Deutschen Wetterdienstes in der U. S. Zone* No. 38:51-63, 1952.
3. Stroud, W. G., Nordberg, W., et al., "Rocket-Grenade Measurements of Temperatures and Winds in the Mesosphere over Churchill, Canada," *J. Geophys. Res.* 65(8):2307-2323, August 1960.
4. Teweles, S., and Finger, F. G., "An Abrupt Change in Stratospheric Circulation Beginning in Mid-January 1958," *Monthly Weather Rev.* 86(1):23-29, January 1958.
5. Labitzke-Behr, K., Petzoldt, K., and Scherhag, R., "Preliminary Daily Northern Hemisphere 10-Millibar Synoptic Weather Maps of the Year 1961. Part 1: January-March," *Meteorologische Abhandlungen des Instituts für Meteorologie und Geophysik der Freien Universität Berlin* 20(1): 1-99, 1961.
6. Murgatroyd, R. J., "Winds and Temperatures Between 20 km and 100 km — a Review," *Quart. J. Roy. Meteorological Soc.* 83(358):417-458, October 1957.
7. Batten, E. S., "Wind Systems in the Mesosphere and the Lower Ionosphere," Rand Corp. Paper P-2018, June 13, 1960; also *J. Meteorology* 18(3):283-291, June 1961.
8. Keegan, T. J., "Large Scale Disturbances of Atmospheric Circulation Between 30 and 70 Kilometers in Winter," J. Geophys. Res. 67(5):1831-1838, May 1962.
9. Nordberg, W., and Smith, W. S., "Preliminary Measurements of Temperatures and Winds above 50 km over Wallops Island, Virginia," NASA Technical Note D-1694 (in press); this report will also be published under the title "Grenade and Sodium Rocket Experiments at Wallops Island, Virginia," in: *Proc. Internat. Sympos. on Rockets and Satellite Meteorology, Washington, April 1962,* Amsterdam: North Holland Publ. Co. (in press).
10. Wexler, H., "A Meteorologist Looks at the Upper Atmosphere," in: *Atmospheric Explorations: Papers of the Benjamin Franklin Memorial Symposium of the American Academy of Arts and Sciences,* ed. by H. G. Houghton, Cambridge: Technology Press of Massachusetts Institute of Technology, 1958, pp. 79-100.

NASA-Langley, 1963 G-343